CW applications and plans for SMTF

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LBNL

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Applications for ß=1 cw scrf

- Stable rf fields
- Inherently small perturbative effects on the beam from wakefields
- Reduced rf drive power requirements (cf. warm)

- Storage rings
- Energy recovery linacs (ERL's)
- Recirculating linacs
- Single-pass linacs

- *bunch manipulation in storage ring light sources*
- *high flux/brightness synchrotron light sources*
- *free-electron lasers*
- *electron-hadron colliders*
- *e^+ - e^- colliders*
- *hadron colliders*
- *electron cooling*
- *nuclear physics facilities*
- *Compton scattering*
- *THz CSR sources*

Applications for ß=1 cw scrf - contd.

- $\tau \approx$ 2.4 s for unloaded 1.3 GHz structures, $Q_0 \sim 10^{10}$
  - Overcoupling reduces filling time
  - Beam loading may provide conditions closer to a match
  - Many applications do not have heavy beam loading

- Q_{ext}, coupling, and filling time are limited primarily by the ability to provide feedback of the system against field fluctuations induced by microphonics
  - Q_{ext} of 2.6×10^7 for the TESLA cavities
  - $\tau \approx$ milliseconds

- Applications of interest discussed here require continuous bunch rates » 1-10 ms time constant

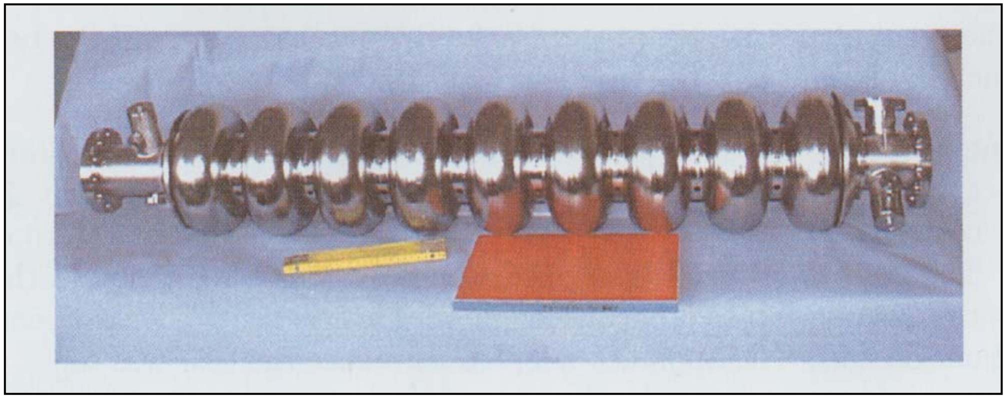
Operate in continuous wave (cw) mode

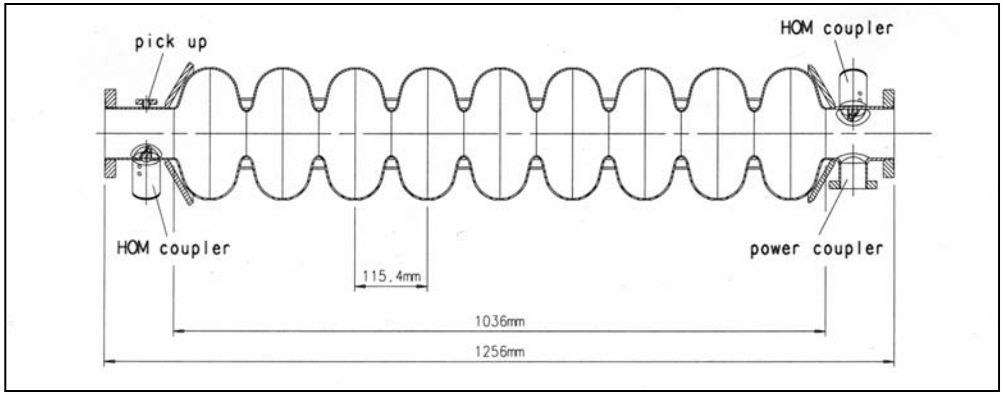
CW scrf-based proposals and facility concepts

- European X-ray FEL: single-pass linac light source
- BESSY FEL: single-pass linac light source
- KAERI: ERL light source
- NHMFL: ERL light source
- 4GLS: ERL light source
- BNL e-RHIC: ERL for e^- cooling
- CEBAF: 12 GeV upgrade
- TJNAF: ERL FEL
- Cornell / TJNAF: ERL light source
- KEK-B: crab cavities
- ALS (LBNL) and APS (ANL): storage ring deflecting cavities
- LHC: crab cavities
- Arc-en-Ciel: recirculating linac / ERL light source
- BNL e-RHIC: ERL light source
- Max-lab: ERL light source
- BINP: ERL light source
- LBNL: recirculating linac light source
- MIT-Bates : single-pass linac light source

CW operation with TESLA technology

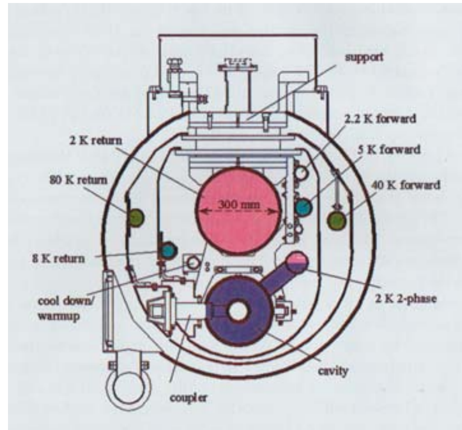
	TESLA	CW (e.g.)
E_{acc} [MV/m]	23.4	20
Operation mode	Pulsed	CW
Pulse length [ms]	1.37	CW
Repetition rate [Hz]	5	CW
Duty factor [%]	0.685	100
Beam current [mA]	9.5	0.03
Bandwidth [Hz]	520	50
Q_o	10^{10}	10^{10}
Q_{ext}	2.5×10^6	2.6×10^7
RF power/ cavity	1.85 MW	10 kW
Dynamic load at 2K per cavity [W]	0.4	42

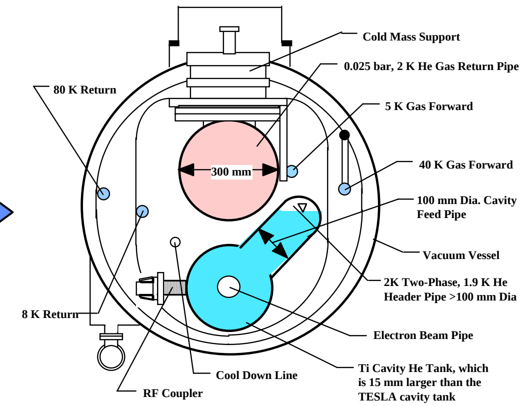




CW scrf thermal management

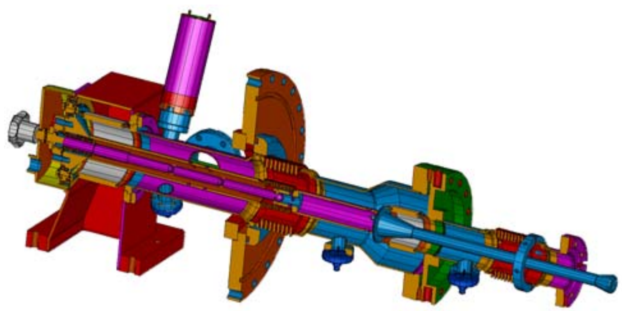
- **Heat transport from cavity**





TESLA TDR, DESY

- **Input coupler**

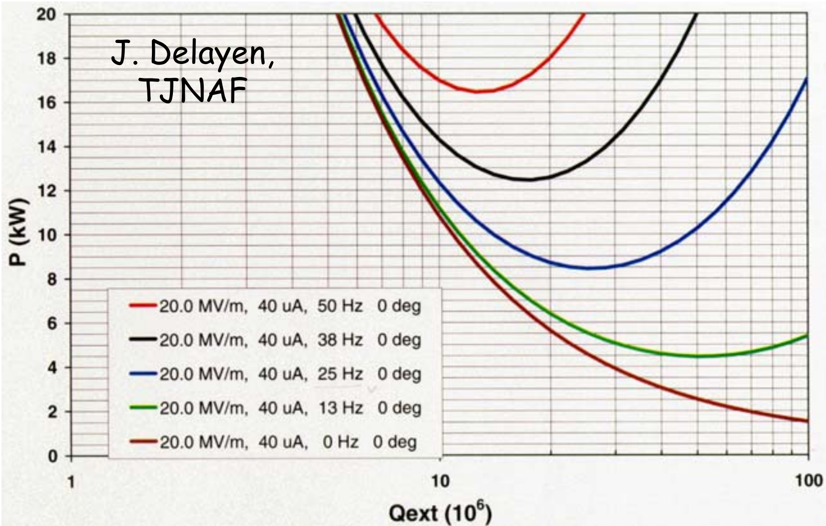


- Example: modifications of TESLA design for cw operations
  - Increase number of feed pipes between the rf cavity helium tank and the two-phase helium stand pipe
  - Position the helium feeds near ends of the helium tank
  - Increase the inside diameter of the helium tank
  - Increase the liquid helium feed pipe diameter
  - Increase the two-phase helium header pipe diameter

- **Increase Q_o**
  - Improved materials processing
  - Lower frequency
  - Reduced temperature
    - Pressure control, magnetic shielding, cryo system, costs, …

Feedback control of tuning variations

- Tight coupling minimizes RF power requirements
  - ß ~ 1 for power optimization
  - May be limited by feedback bandwidth required for stability
- Random tuning variations
  - Slow perturbations e.g. from variations in He pressure
  - Faster perturbations from microphonics at acoustic frequencies - structural resonances
- Tight phase and amplitude control
- $\Delta\phi < 0.01°$, $\Delta V/V < 10^{-4}$
  - FEL output pulse energy stability
  - Synchronization, seeding



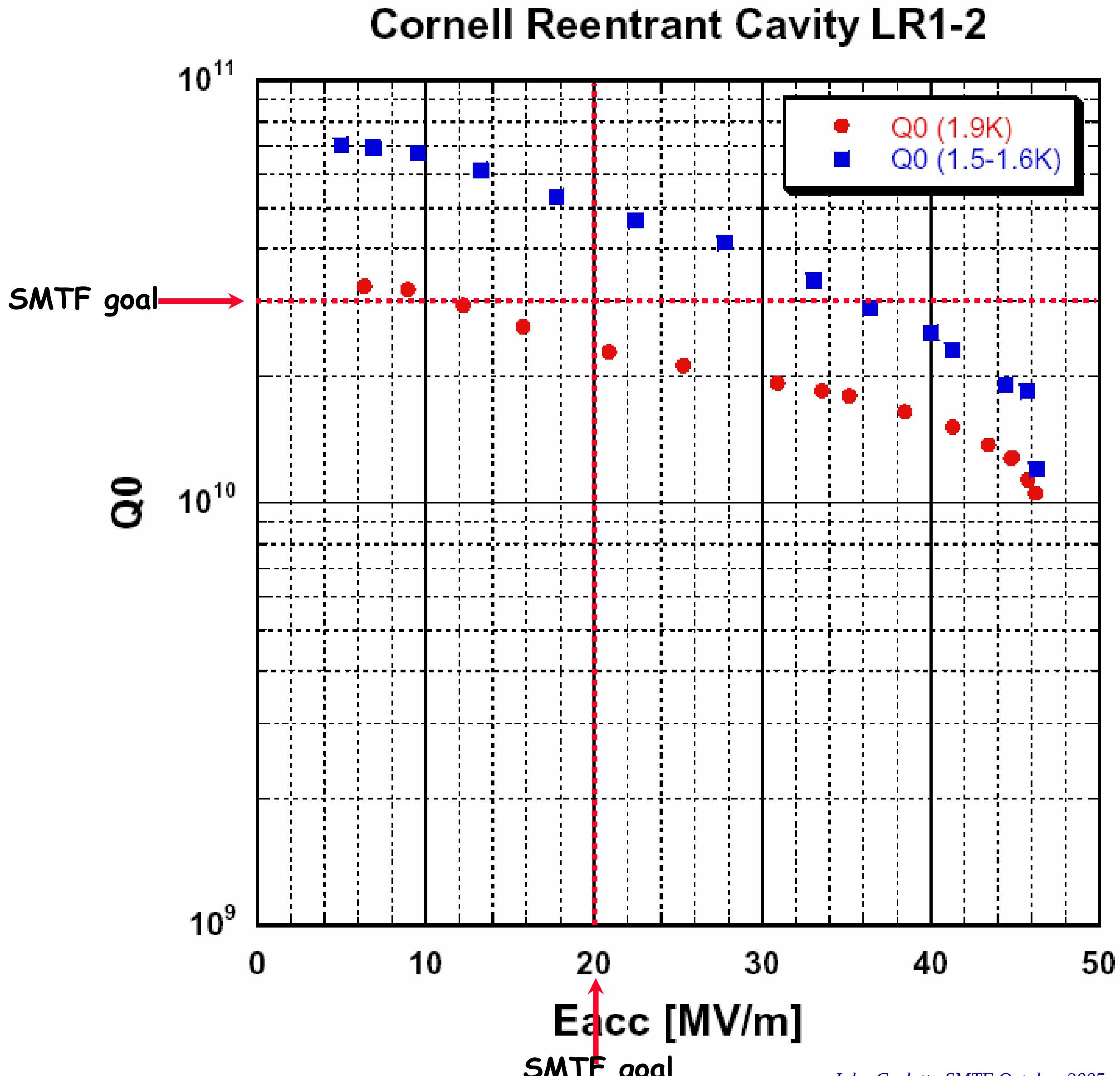
$$P_g = \frac{P_c}{4\beta}\left\{(1+\beta+b)^2 + \left[2Q\frac{\Delta f}{f} - b\tan(\Psi_B)\right]^2\right\}$$

$$\beta_c = \frac{Q_0}{Q_{ext}}; \quad b = \frac{P_{beam}}{P_C}$$

High Q_o reduces power dissipation in liquid helium

- SMTF goal for CW systems
  - Q_o 3×10^{10} at 20 MV/m
  - Installed cryomodule

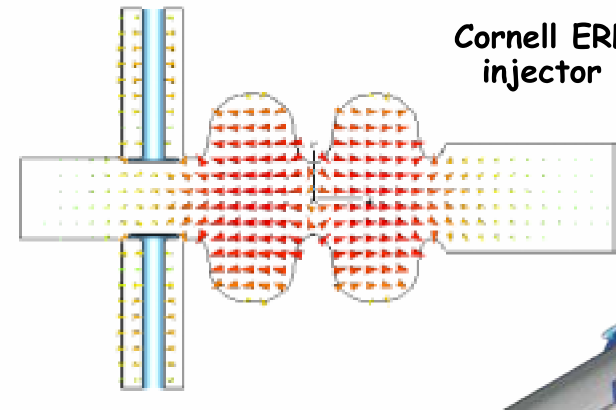
$$R_{BCS} \propto \frac{1}{T} f^2 e^{-\frac{a}{T}}$$



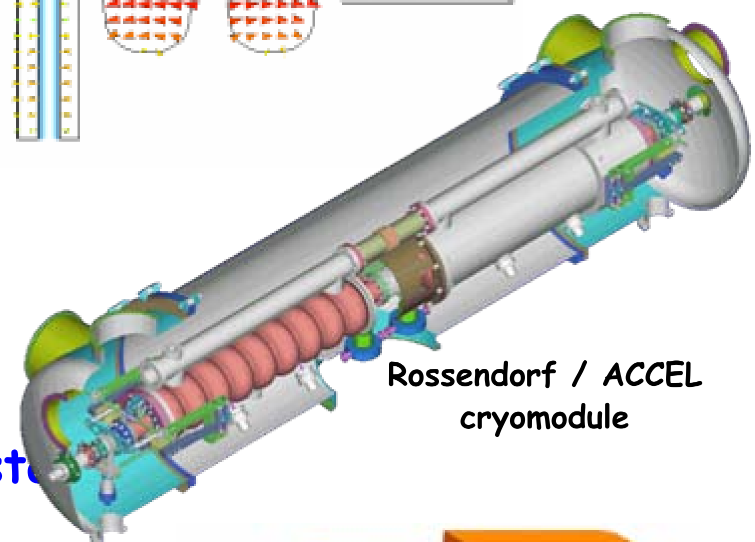
CW scrf accelerating structures under development

Superconducting rf linac

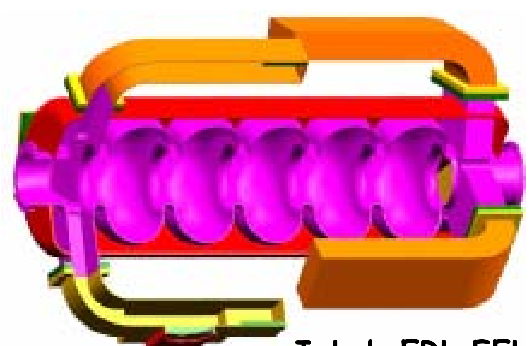
- Small perturbations from wakefields
  - Large iris aperture
- CW operation
    - High gradient (~20 MV/m)
  - High repetition rate
  - High beam power
  - Flexible pulse rate
  - Flexible pulse pattern
  - Highly stable cavity fields
    - RF feedback and controls
      - Electron beam energy and timing st
- HOM suppression
- Energy recovery option



Cornell ERL injector



Rossendorf / ACCEL cryomodule



J-Lab ERL FEL

SMTF goals to demonstrate cw accelerating cryomodules

- $E_{accelerating} \geq 20$ MV/m
- $Q_o \geq 3 \times 10^{10}$
- $Q_{ext} \geq 2.5 \times 10^7$ for low beam loading applications
- High stability and control of microphonics, with a goal of phase error < 0.1° and amplitude error $< 10^{-4}$
- Wakefield suppression for haevily loaded applications
  - HOM's and LOM's
- The above performance in the presence of beam
  - Modest average current but high peak current
  - ~ nC, ~ 10 kHz
    - 1 nC, repetition rate ~ 10 kHz (c.f. ~100 MHz in storage rings)
- These parameters are not addressed in existing cw scrf programs
- Extends the reach of the existing US program in cw scrf

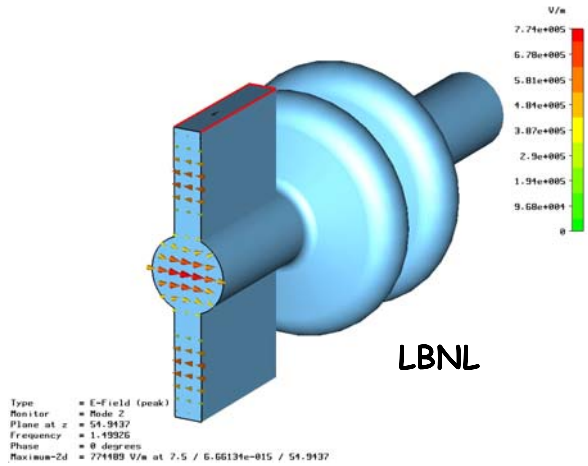
Infrastructure for cw accelerating cryomodule development

- RF power
  - L-band 1.3 GHz (ILC)
  - ~ 15 kW per m @ 20 MVm^{-1}
    - 50 Hz bandwidth
  - IOT or klystron (2 required initially, one for each cavity)
  - dc power supply
  - drive amplifier
- Space for other rf hardware at different frequencies
  - To test harmonic cavities for 3rd generation light sources
- Cryogenic fluids & transport
  - 120 W @ 2 K (40 W @ 1.8 K) (includes safety factor 1.5)
  - 10 W @ 4.5 K
  - Pumps to reach He vapor pressure corresponding to 1.8K

SRF "harmonic" structures under development

"Harmonic" cavities

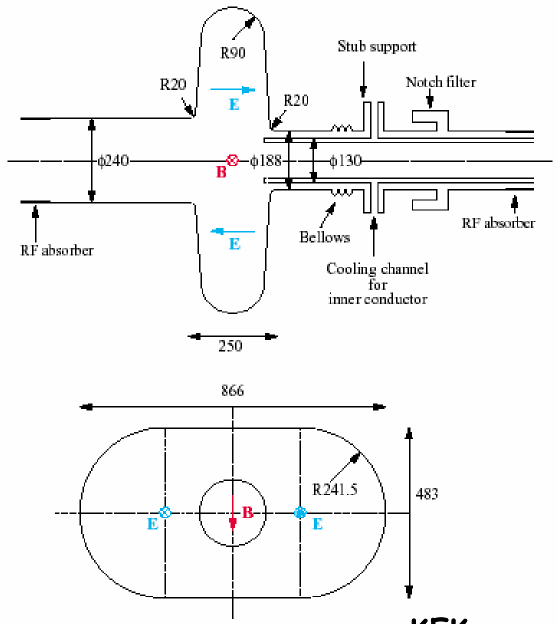
- Operate at a higher harmonic of the accelerating RF frequency



LBNL

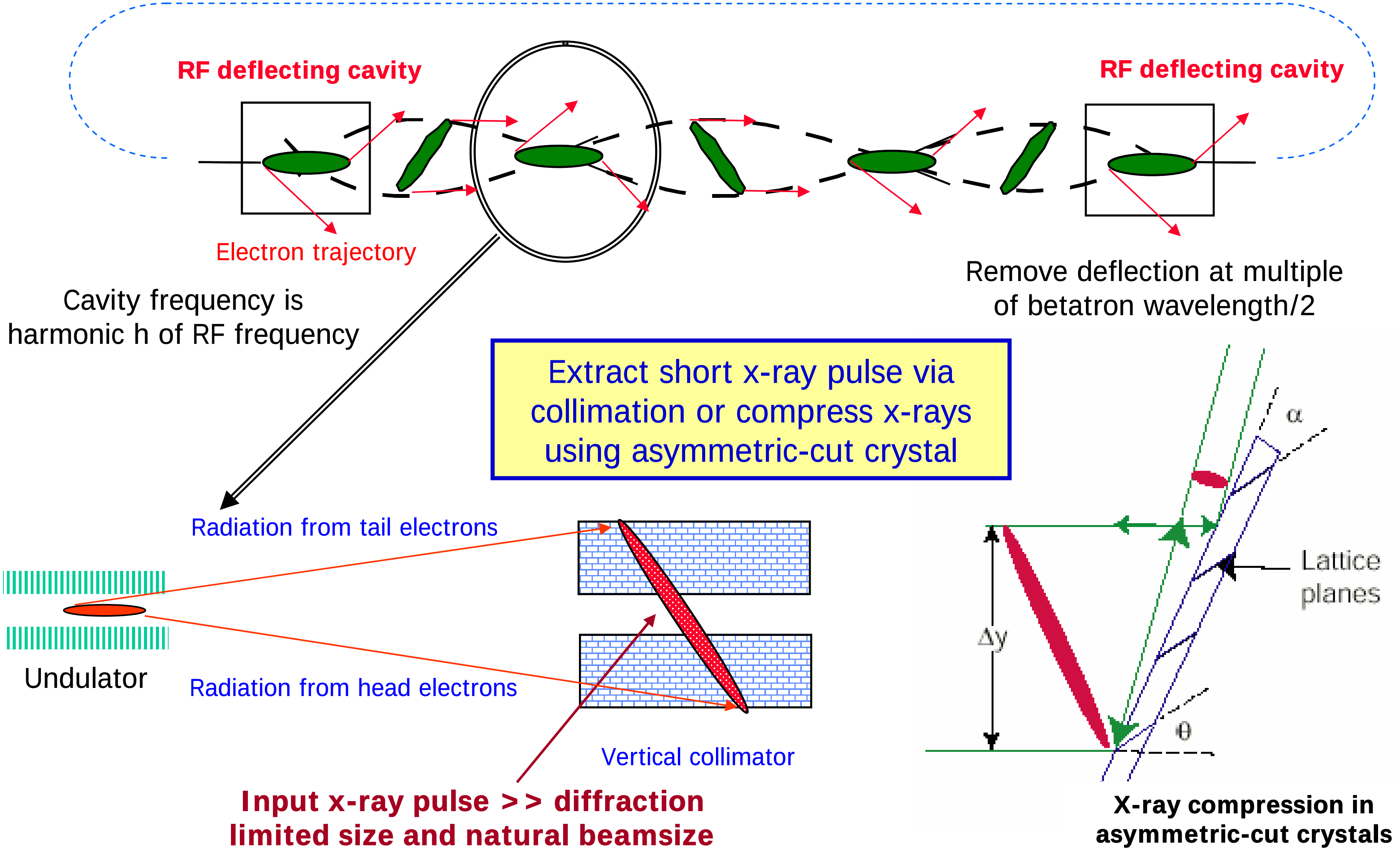
FNAL

- Monople mode cavities
  - Linearize longitudinal phase space in bunch compressors
  - Provide potential well distrortion for bunch length control in storage rings
- Dipole mode cavities
  - Deflecting cavities for electron beam diagnostics and for bunch manipulation



KEK

BES light source application
X-ray pulse compression via vertical chirp



A. Zholents, P. Heimann, M. Zolotorev and J. Byrd, Nucl. Instruments Methods Phys. Res., Sect. A 425, 385 (1999).

SMTF near-term goals to demonstrate CW deflecting cavity cryomodules

- Light source applications
  - ALS (Berkeley), APS (Argonne), etc.
- Dipole mode cavities give head-tail kick to beam
  - "Crabbing"
  - Allows use of the small vertical dimension in a storage ring beam
    - Generate "ultrafast" x-ray pulses
- Synergies with existing Basic Energy Sciences (BES) facilities needs
- ALS and APS pursuing these concepts
  - Propose SMTF as test-bed for superconducting cryomodules
- *SMTF infrastructure requirements for deflecting cavities to be determined*

Cavity HOM and wakefields

- Wakefields may persist for long periods
- Many modes in multi-cell structures
  - Higher-order and *lower-order* modes
- May present problems with collective effects
  - High-current applications, multi-bunch effects, BBU
  - Single-bunch emittance growth
  - Energy spread
- Control of cavity fields under beam loading
  - Transient behavior
- Beam tests important

Beam tests for cw scrf test facility

- High bunch rate desirable
  - Study transient effects with 1 nC bunches
- Bunch lengths of 1 – 10 ps
- Transverse emittance ~ mm-mrad (normalized)
  - Requires gun and injector development
    - Laser, rf gun cavity, modulator
    - Could be superconducting gun

- High average current measurements may be made at other facilities (e.g. TJNAF, BNL)

Summary - cw possibilities at SMTF

- SMTF cw component would provide capabilities to research parameters not addressed by existing programs
- Major applications in existing and future light sources
- "ILC"-like accelerating cavities for linac-based facilities
  - 20 MVm^{-1} cw
    - $Q_o > 3 \times 10^{10}$
    - $Q_{ext} > 2.5 \times 10^{7}$
- Harmonic & deflecting cavities for existing light sources
- Beam tests provide additional performance validation

- Initial focus on deflecting cavities for light-source applications
  - Aligns with needs of existing BES facilities ALS and APS
  - Developing proposal to submit to BES

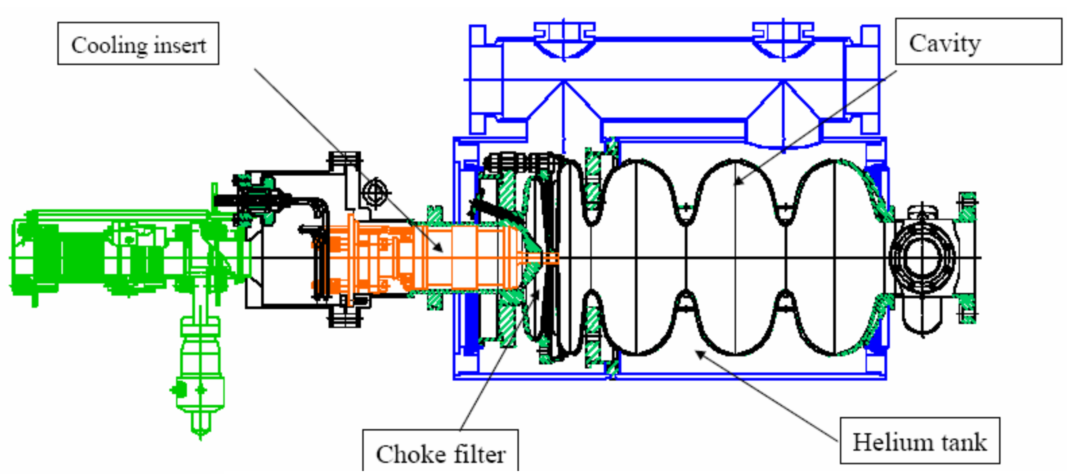
SRF technologies under development

SRF electron gun

- Flexible pulse format
- High repetition rate
  - Potential for high beam power
- Low emitance
- Low energy spread
- Stable fields
- Lock photocathode laser and RF phase

- *Photocathode laser*
- *Cathode*

BROOKHAVEN NATIONAL LABORATORY — Jefferson Lab — Advanced Energy Systems, Inc.



BESSY / PITZ http://www.bessy.de/front_content.php?idcatart=241